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THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

III. SKETCH OF THE PRESENT STATE OF KNOWLEDGE CONCERN- ING THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.¹

WITHOUT attempting to distinguish critically between the different types of the basic rocks occurring in the Lake Superior region, it will be sufficient for the present to call attention to some of the work done on them, more especially with reference to their microscopical examination. It will not be necessary to refer to all of the articles in which the "traps" of the region have been more or less briefly mentioned, as it will serve our present purpose to allude only to the most important papers on the subject, and to outline, where advisable, the descriptions of the most important rocks as given by various authors. Professor Irving² has discussed the theories held by some of the writers with respect to the origin of the traps, but since these, when they differ from the generally accepted theory of an igneous origin for the rocks in question, are found to be opposed to the facts observed, it would be unprofitable to discuss them further. There can be no doubt but that all of the basic, massive rocks found in dykes and beds in the Lake Superior region are truly igneous.

Douglass Houghton³ first called attention to the wide-spread occurrence of traps around Lake Superior in his Fourth Annual Report as Geologist of Michigan. He identified knobs, dykes and flows of trap, but was unable to distinguish between the numerous varieties of the rock. His observations related principally to the traps in the Archæan and Keweenawan areas in Michigan.

¹ This Journal, Vol. I., p. 433.

² The Copper-Bearing Rocks of Lake Superior. Monographs U. S. Geological Survey, Vol. V., p. 7.

³ Dated 1841. Reprint in Memoir of Douglass Houghton, by Alvah Bradish, Detroit, 1889, pp. 167-168, and 176-182.

Following Houghton, Messrs. Foster and Whitney¹ made an examination of the copper and iron regions of Michigan under the direction of the United States government. In their report on the copper lands, they described briefly the occurrences of dykes and flows of traps in the copper-bearing rocks of the south shore of the lake. Among them they distinguished compact, amygdaloidal, porphyritic, epidotic and brecciated varieties (pp. 69 and 70). In Part II. of the report, in their description of the iron region, they refer to the large dykes in the Animikie rocks on the north shore of the lake (pp. 12-13), and to the dykes of diabase cutting the Archæan schists in the neighborhood of Marquette, Michigan (pp. 18 and 39). They also gave a recapitulation of the characteristics of the traps of the entire region (pp. 85-94), with their chemical and mineralogical composition.

At about the same time that Messrs. Foster and Whitney were engaged in their survey of the copper and iron rocks, Dr. D. D. Owen,² with his assistants, was employed in making a geological reconnoissance of the states of Wisconsin, Iowa, and Minnesota. Messrs. D. D. Owen, J. G. Norwood, B. F. Shumard, Col. Whitteley, and Major R. Owen examined a much larger area than did Messrs. Foster and Whitney, and were therefore not able to give as much detailed description of the rocks observed as the last named geologists succeeded in doing. They, however, mention the occurrence of sheet and dyke gabbros in Wisconsin, and of dyke gabbros in the Animikie of Minnesota.

Following these geologists came many others who examined the Lake Superior region in more or less detail, but added little to the knowledge of the trap rocks of the district, until, in 1871, Professor R. Pumpelly³ published a paper on "The Paragenesis and Derivation of Copper and its Associates on Lake Superior," in which he described the melaphyres and other basic rocks associated with the copper on Keweenaw Point. After Pumpelly a number of geologists visited the region, but they devoted their

¹Report on the Geology and Topography of a Portion of the Lake Superior Land District, Part I. Washington, 1850. Part II., Washington, 1851.

²Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. By D. D. Owen. Philadelphia, 1852, pp. 142-164, 285, 304-306, 342-417.

³Am. Jour. Sci. (3) II., 1871, p. 188.

time principally to the discovery of the relations existing between the several rocks, and made no efforts to divide these into their varieties.

With the establishment of the surveys of Minnesota, Michigan, and Wisconsin, however, an attempt was made to classify with scientific accuracy the basic rocks of these three states. Kloos¹ had already discovered the gabbro of Duluth and had identified a melaphyre from the same place, but had made no very exact determination of either. Among the geologists on the Michigan and Wisconsin surveys, Messrs. Julien, Wright, Wichman, Pumpelly and Irving examined microscopically the rocks of the Huronian and the Keweenawan series of Wisconsin, and of the Archæan, Huronian and Keweenawan of Michigan, and among the descriptions of these rocks which they give may be found very exact accounts of the characteristics of the diabases, gabbros and other basic eruptives of the region.

Messrs. A. A. Julien² and C. E. Wright,³ as early as 1873, mentioned quite fully the greenstones and traps of the Archæan and of the iron-bearing formations in Michigan. The former writer identified many massive and schistose rocks to which he gave the name of diorite, since he found in them hornblende, but no augite. Mr. Wright likewise discovered hornblende rocks which he evidently regarded as original, since he calls them all diorites. Mr. Wright's determinations are the first ones based upon microscopical observations of Lake Superior rocks. Messrs. Brooks⁴ and Pumpelly⁵ contented themselves with macroscopic examinations of the basic rocks of the iron and copper-bearing series in this state, and in this way distinguished diorites, melaphyres and amygdaloids, while Mr. Marvine⁶ divided the

¹J. H. KLOOS: *Geologische Notizen aus Minnesota*. Zeits. d. deutsch. geol. Gesell. XXIII., 1871, p. 417. Trans. by N. H. Winchell, 10th Ann. Rep. Geol. and Nat. Hist. Survey of Minnesota, for 1881, p. 193.

²A. A. JULIEN: *Geological Survey of Michigan*, Vol. II., 1873, Appendix A, p. 41.

³C. E. WRIGHT: *Ib.* Appendix C, p. 213-231.

⁴T. B. BROOKS: *Geological Survey of Michigan*, Vol. I., 1873; Part I., *Iron-Bearing Rocks*, pp. 99-104.

⁵R. PUMPELLY: *Part II., Copper District*, *Ib.* pp. 7-16.

⁶A. R. MARVINE: *Part II., Copper District*, *Ib.* pp. 95-116.

rocks of the Eagle River section of Keweenaw Point into greenstone or fine-grained diorites, feldspathic traps or coarse grained diorites, and traps, including the melaphyres and amygdaloids.

Before the publication of the reports of the Wisconsin survey, Messrs. Streng and Kloos¹ communicated the results of their examination of certain Keweenawan rocks occurring in Minnesota and in Wisconsin about the head of Lake Superior. Streng, who did the microscopical work of the investigation, recognized among his specimens melaphyres, augite-diorites, quartz-diorites and a hornblende-gabbro to which reference has already been made in a former article.² Pumpelly³ also had devoted his attention to the rocks of the copper series. He studied, more particularly the fine and coarse-grained diabases and melaphyres of Keweenaw Point.

With the publication of Volume III. of the Geological Survey of Wisconsin a more general classification of the Keweenawan rocks of Northern Wisconsin and of Keweenaw Point in Michigan was given by the same author.⁴ He distinguished among them diabases, hornblende and orthoclase-gabbros, melaphyres, augite-diorites and porphyrites, the characteristics of which will be mentioned when the discussion of the diabases and gabbros of Keweenawan age is taken up. In the same volume Irving described the rocks of the Huronian of Wisconsin, among which he found gabbros (p. 147), and those of the Keweenawan in the same state (pp. 168 to 193). The hornblende-gabbros and the augite-diorites of Pumpelly he regarded as altered gabbros and diabases, and not as original hornblende rocks. Julien⁵ also gave a very excellent account of the microscopic appearance of two olivine-diabases

¹ A. STRENG and J. H. KLOOS: Ueber die Krystallinischen Gesteine von Minnesota in Nord Amerika. Neues Jahrb. f. Min., etc., 1877, pp. 31, 113, 225.

² This Journal, Vol. I., p. 447.

³ R. PUMPELLY: Metasomatic Development of the Copper-Bearing Rocks of Lake Superior. Proc. Am. Acad. of Arts and Sciences, 1878, XIII., Part II., pp. 253-309.

⁴ Geology of Wisconsin, III., 1880, p. 29.

⁵ A. A. JULIEN: Microscopic Examination of Eleven Rocks from Ashland county Wisconsin. Geol. of Wisconsin, III., 1880, p. 224.

from Ashland county, Wisconsin; and Wichman¹ published a classification of Huronian rocks based on their microscopical examination. Wichman divided the massive basic rocks into diabases, coarse-diabases and diorites. The only other microscopical work done in connection with the Wisconsin Survey is that by the late C. E. Wright, published in the second volume of the reports. In this Mr. Wright² mentioned the occurrence of a diorite containing augite in the bed of Black river.

Further, Dr. Wadsworth,³ in his discussion as to the origin of the jasper and iron-ores of the Marquette region describes briefly the microscopic features of many of the intrusive knobs that are so prominent a feature in the topography of the district. These are declared to consist largely of diabase and coarse basalt, both massive and slightly schistose.

The investigation of the basic rocks of the region had by this time been sufficiently exact, and the number of specimens examined was large enough to give an idea of the characters of the commonest types occurring there, but these investigations had been undertaken by so many different geologists that no exact correlation between the various varieties discovered was possible. No classification of these could be accomplished until some had examined specimens from all the different localities and had compared them with one another. This work was undertaken by Professor Irving⁴ in 1881, and was ably accomplished by him in the course of two years. All publications referring to the lithology of the Keweenaw and Huronian formations on both sides of the lake were carefully reviewed, most of the specimens described in them were examined, and the results of this study and examination, together with a great deal of new information gathered

¹ A. WICHMAN : Microscopical Observations of the Iron-bearing (Huronian) Rocks from the Region South of Lake Superior. *Ib.* p. 600.

² CHARLES E. WRIGHT : *Geol. of Wisconsin*, II., 1878, p. 637.

³ M. E. WADSWORTH : Notes on the Geology of the Iron and Copper Districts of Lake Superior. *Bull. Mus. Comp. Zoölogy*, 1881, Vol. VII., p. 36-49.

⁴ R. D. IRVING : The Copper-bearing Rocks of Lake Superior. Monograph V., U. S. Geol. Survey, Washington, 1883.

during a trip among the dykes and sheets of the north shore of the lake, were incorporated in a monograph and published under the auspices of the U. S. Geological Survey in 1883.

The greater portion of the volume is concerned with the discussion of the Keweenawan rocks, but a brief synopsis of the character of the Huronian Series is given (pp. 367-409), and in this a few descriptions of Huronian basic eruptives are communicated. A brief synopsis of Irving's results will serve to give an idea of the relations of the different basic rocks to each other, and at the same time will serve as a basis for the present paper.

The original basic rocks of the Keweenawan, according to Irving, embrace gabbros and diabases, an anorthite rock consisting almost exclusively of anorthite, malaphyres and amygdaloids. The rocks described under the various names possess in general the characteristics of the respective types as defined by Rosenbusch in the first edition of his *Mässige Gesteine*. The gabbros are coarse-grained rocks with a dark-gray or black color in the least coarse-grained varieties, and a light-gray color when the plagioclastic ingredient becomes greatly predominant as is apt to be the case in the coarser kinds. Their texture is highly crystalline, and their specific gravity varies between 2.8 and 3.1. The fine-grained basic rocks, whose ordinary type is diabase, make up relatively thin flows, that are almost invariably furnished with vesicular or amygdaloidal upper portions. Externally the diabases are dark in shade, being black, purple, dark green or brown, according as the rock has undergone more or less alteration. In texture they vary from medium fine-grained to cryptocrystalline. The coarser kinds grade into coarse-grained gabbros, but this gradation has never been observed in any one bed. Moreover, the diabases have undergone a great deal more alteration than the coarser gabbros, and are very strongly marked by their external characteristics, both in their fresh and altered states. They therefore seem to Irving to deserve a special name; since they possess the structure of diabases he calls them by this designation. The olivine-free diabases of the ordinary type pass into still finer grained kinds of a black or brown color. Some of these are

entirely aphanitic, and all kinds tend to a porphyritic development, carrying as phenocrysts oligoclase and more rarely labradorite and augite. Like the diabases mentioned above, the diabase-porphyrates are furnished with amygdaloidal upper portions. In the few instances in which the olivine-bearing rocks have an undifferentiated glassy base, they are called melaphyres, although placed among the fine-grained diabases.

The most of the basic rocks of the region are in the form of interbedded sheets. Dykes are rare. When they occur, their material appears to be diabase or diabase-porphyrate. It is rarely coarse enough to be classed with the rocks called gabbro.

In the Huronian areas on the other hand, large dykes of coarse-grained gabbros¹ cut through the sedimentary beds, and with these are intercalated thick beds of gabbro, and occasionally a few thinner ones of diabase.

Since Irving's general classification of the rocks in question a few other publications have appeared in which the petrography of small areas, and the descriptions of hand-specimens are treated.

Messrs. Herrick, Tight and Jones² busied themselves during one summer with a study of the rocks around Michipicoten Bay, an arm of Lake Superior extending northeasterly into Canada. Their paper contains but little with respect to the basic eruptives not found in Irving's monograph. Dr. Wadsworth³ has examined some of the specimens gathered by the Minnesota Survey and has divided the basic rocks into peridotites, basalts, including gabbros, diabases, melaphyres, diorites and norites, peridotites, and rocks regarded as altered andesites. All of Dr. Wadsworth's descriptions are marked by exactness, but the conclusions based upon them are rendered less valuable than they would have been had Wadsworth himself not been compelled to depend upon others

¹ It will be shown later that most of the rocks called gabbro by Irving and others, are not gabbros, but are coarse-grained diabases.

² C. L. HERRICK, W. G. TIGHT and H. JONES: *Geology and Lithology of Michipicoten Bay*. Bull. Scient. Lab. of Denison Univ., Vol. II., Part 2, 1887, p. 120.

³ Dr. M. E. WADSWORTH: *Preliminary Description of the Peridotites, Gabbros, Diabases and Andesites of Minnesota*. Bull. No. 2, Geol. and Nat. Hist. Survey of Minn., 1887.

for a knowledge of the field relations of the specimens studied. Messrs. Herrick, Clarke and Deming¹ have also studied a few specimens of the gabbro, both ordinary and orthoclastic varieties, from Duluth, but they have added little to what was already known concerning them, except the suggestion of the possible dependence of the orthoclase-bearing varieties upon their environment for the peculiar characteristics which they possess.

The Canadian geologists have likewise been engaged in a study of the rocks on the north side of Lake Superior. Many allusions have been made to the massive sheets and dykes in the Thunder Bay region, but no microscopical descriptions of them have been published, with the exception of a few notes by the present writer appended to a report by Mr. Ingall² on Mines and Mining in the Thunder Bay Silver District. In this report the relations of the large dykes and thick beds of diabase or gabbro to the fragmental rocks of the Animikie series north of the lake are carefully sketched, and the microscopic features of the most important rocks are described. In the Appendix,³ a few altered gabbros and diabases from both sheets and dykes are very briefly characterized. The former of these have the general peculiarities of the gabbro from the great dyke on Pigeon Point, Minnesota, referred to by the writer⁴ in an article on certain contact phenomena at this place, and described at greater length⁵ in a bulletin of the U. S. Geological Survey. In the first of these two papers, in addition to the reference to the Pigeon Point dyke, a few remarks are made concerning the relations of Irving's orthoclase-gabbros to the more common varie-

¹ C. L. HERRICK, E. S. CLARKE and J. L. DEMING: Some American Norytes and Gabbros. *Am. Geol.*, June, 1888, p. 339.

² E. D. INGALL: Report on Mines and Mining on Lake Superior. *Geol. and Nat. Hist. Survey of Canada*. Montreal, 1888.

³ W. S. BAYLEY: Notes of Microscopical Examination of Rocks from the Thunder Bay Silver District.

⁴ W. S. BAYLEY: A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenites. *Am. Jour. Sci.* XXXVII., 1889, p. 54.

⁵ W. S. BAYLEY: The Igneous and other Rocks on Pigeon Point, Minnesota, and their Contact Phenomena. *Bull. No. 109, U. S. Geol. Survey*, 1893.

ties of the gabbro of the region, but no detailed descriptions of these rocks, nor of the ordinary gabbros, whose modified forms they are supposed to be, are given. Finally, Dr. A. C. Lawson¹ has mentioned some of the characteristics of certain diabases from dykes in the Archæan rocks of the Rainy Lake region, in which the gabbroitic as well as the diabasic structures are well exhibited, the former toward the centers and the latter near the sides of the masses.

The most comprehensive treatment of the "greenstones" and "greenstone schists" of the Lake Superior region is that by Dr. G. H. Williams² in his bulletin on the origin of the green schist, supposed to underlie the Huronian in Michigan. In this volume the author not only describes the petrographical features of the schists with which he deals, but he likewise describes in some detail the microscopical characteristics of the diabases, diabase porphyrites, diorites, diorite porphyrites and gabbros, associated with the schists, and from some of which the latter have been derived.

Within the past three years a number of papers have appeared in which reference is made to some of the special features of a few of the coarse basic rocks, both north and south of the lake, but no articles have been published that deal with their general features. Fairbanks³ has communicated a few notes on the diorites and gabbros in the province east of the north side of Lake Superior. Irving and Van Hise⁴ have given a brief synopsis of the characteristics of the diabase dykes and interbedded sheets in the Penokee iron series on the south side

¹A. C. LAWSON: Notes on Some Diabase Dykes of the Rainy Lake Region. Proc. Can. Inst. for 1887, and Report on the Geology of the Rainy Lake Region. Pt. F., Ann. Rep. Geol. and Nat. Hist. Survey of Can. for 1887-88, pp. 57-73 and 147-164.

²G. H. WILLIAMS: The Greenstone Schist Areas of the Menominee and Marquette Region of Michigan. Bull. No. 62. U. S. Geol. Survey, 1890.

³H. W. FAIRBANKS: Notes on the Character of the Eruptive Rocks of the Lake Huron Region. Amer Geologist, I. 1890, p. 162.

⁴R. D. IRVING and C. R. VAN HISE: The Penokee Iron-bearing Series of Northern Wisconsin and Michigan. Monograph XIX., U. S. Geol. Survey, 1893. Chap. VII., The Eruptives.

of the lake, and of the gabbro, diabases, diorites, melaphyres and porphyrites of the Keweenawan overlying the Penokee series to the north, while Hall¹ has described a few hand specimens of diabases and gabbros from the Archæan of Central Wisconsin.

Further, in a discussion as to the nature of the diabase sheets interbedded with the Animikie slates and quartzites in Minnesota and Canada, which leads to the conclusion that the former are subsequent intrusions between the clastic beds, Lawson² gives a short generalized description of the petrographical characteristics of these rocks, and in a second article³ he treats of the structure and composition of the anorthite rock of Irving, to which he gives the name anorthosyte. Finally, the writer in two articles refers to the coarse gabbro⁴ of north-eastern Minnesota and to the peridotites and pyroxenites⁵ associated with it along its northern border.

W. S. BAYLEY.

¹ C. W. HALL: Notes of a Geological Excursion into Central Wisconsin. Bull. Minn. Acad. Nat. Sciences, III., No. 2., p. 251.

² A. C. LAWSON: The Laccolitic Sills of the Northwest Coast of Lake Superior. Bull. No. 8, Geol. and Nat. Hist. Survey of Minnesota, p. 30.

³ A. C. LAWSON: The Anorthosytes of the Minnesota Coast of Lake Superior *Ib.*, p. 2.

⁴ W. S. BAYLEY: A Fibrous Intergrowth of Augite and Plagioclase, resembling a Reaction-rim, in a Minnesota Gabbro. Amer. Jour. Science, XLIII. 1892, p. 515.

⁵ W. S. BAYLEY: Notes on the Petrography and Geology of the Akeley Lake Region, in North-eastern Minnesota, 1892, p. 193.